Task 2, November Update
Time variation and modal noise study

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Task 2 goals

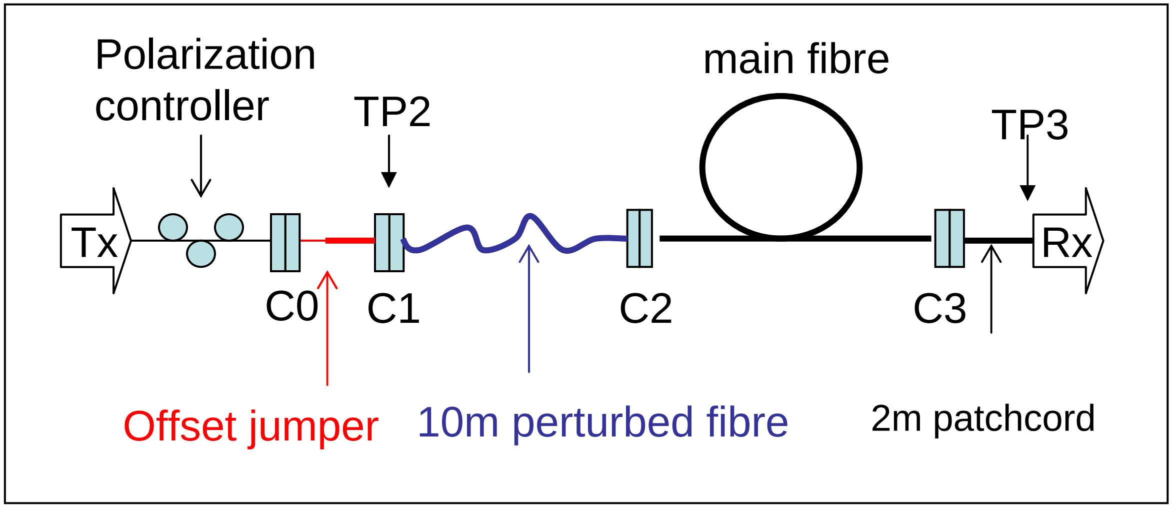
Study the impact of time varying effects on the LRM spec

- Provide input to the TP3 time varying component of the receiver compliance test
  - Set a frequency below which EDC should track (TP3 test rate) and/or
  - Define tracking 'mask' - size vs frequency of perturbation
- Define spectrum/extent of time variation effects
  - Mechanical vibration environment
- Modeling of extent of time variance of links
  - Effect of temperature on link components
- Study of modal noise of the MMF channel
  - Assess modal noise penalty for different laser types

Task 2 Progress

1) Agreed test configuration for modal noise modeling and experiments
2) Referencing GR-63-CORE for operational vibration testing
   - describes vibration tests for in-building environment at constant acceleration, (0.1g & 1g) from 5-100 Hz (vibration amplitude ~$1/f^2$)
3) Study of temperature effects
   - Comprehensive list of mechanisms compiled and size of each effect determined Most temperature effects are not an issue
4) Vibration tests to determine relationship of mechanical perturbation frequency to impulse response variation
   - experiments at 10-100Hz, 1g acceleration (referencing GR-63-CORE)
   - frequency multiplication observed, greatest effect at fundamental
   - max freq of interest 40Hz, for 'just noticeable' level of data envelope modulation
   - lower frequencies for larger channel effects
5) Quasi-static Impulse Response measurements:
   - Polarisation effect - experiment shows it has similar effect on channel as multimode fibre perturbation
   - Input patch cord shaking experiments show worst case 10Hz 'best to worst' impulse response evolution
6) Modal noise calculations adapted for equalized links in order to include noise enhancement, supports 0.5dB maximum penalty allowance

1) Test configuration for modal noise modeling & measurement



Connectors	Offset, um	Notes
C0	N/A	SMF
C1	7	Worst case
C2	7	Worst case
C3	4	Low loss to keep within loss budget
main fibre	length, m	
62.5 um	220/300	tbd
50 um	220/300	tbd

To maximize modal effects, the 2 multimode connectors closest to the transmitter were chosen to have maximum offset.

C3 connection set to a lower loss condition to avoid exceeding connector loss budget.

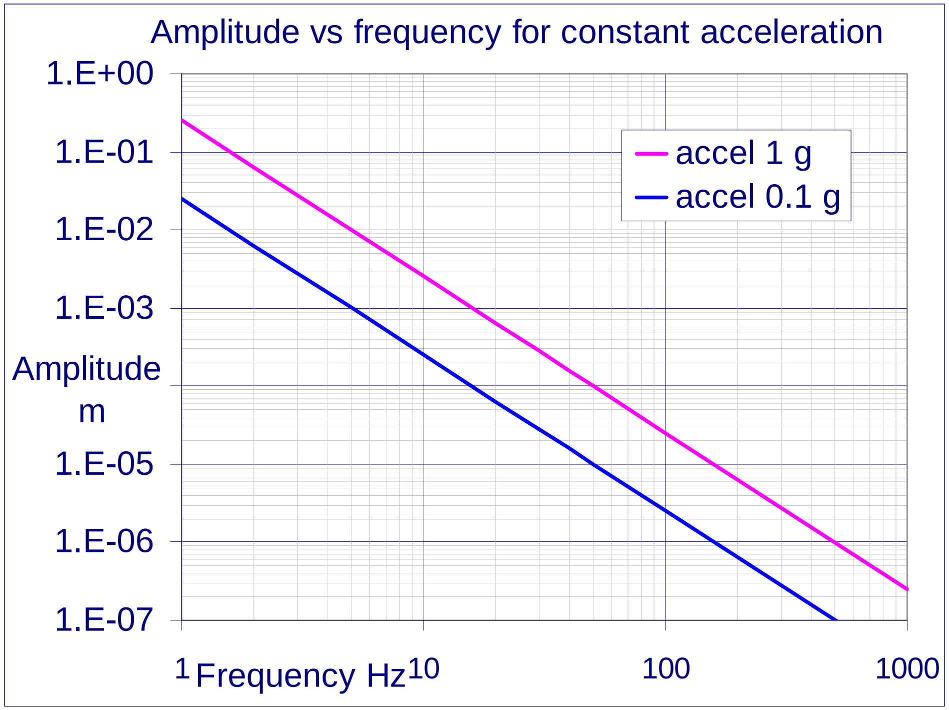
Vibration of connectors is not expected to affect offsets

It is only required that the first length of fibre between C1 and C2 is shaken

2) Vibration tests representing office environment

Referencing GR-63-CORE

- Bellcore standard describing test conditions for telecomms central office equipment in a controlled indoor environment
- Describes vibration tests at constant acceleration (0.1g & 1g) from 5-100 Hz
- Vibration amplitude ~ **$1/f^2$**



  - 0.1g acceleration at 1Hz corresponds to a 25mm perturbation amplitude this is similar to TIA/EIA-455-203 fibre shaker
  - 1g acceleration at 1Hz corresponds to 250mm amplitude - similar to vigorous manual shaking of a fibre coil
  - 1g acceleration at 1kHz corresponds to 0.25micron amplitude - very small !

Suggests that low frequency range are the test case of interest

Refs: king_1_0904, LRM080404

3) Temperature variation impact

Interim findings given in Popescu_02_0904 (September Interim meeting)

- Impact of temperature change on receiver, main fibre and most transmitter laser parameters found to be small enough to ignore

Recent progress

- Micro-bend losses can be induced by two temperature dependent mechanisms (humidity penetration and the differing thermal expansion coefficients of the silica fiber and most plastics, see popescu_2_0904). These effects occur at low temperature, below the 0 deg. C, outside the nominal operating range.

Remaining link related items

- Impact of polarization change due to connector temperature variation and impact on modal noise, work in progress following results from task 4.

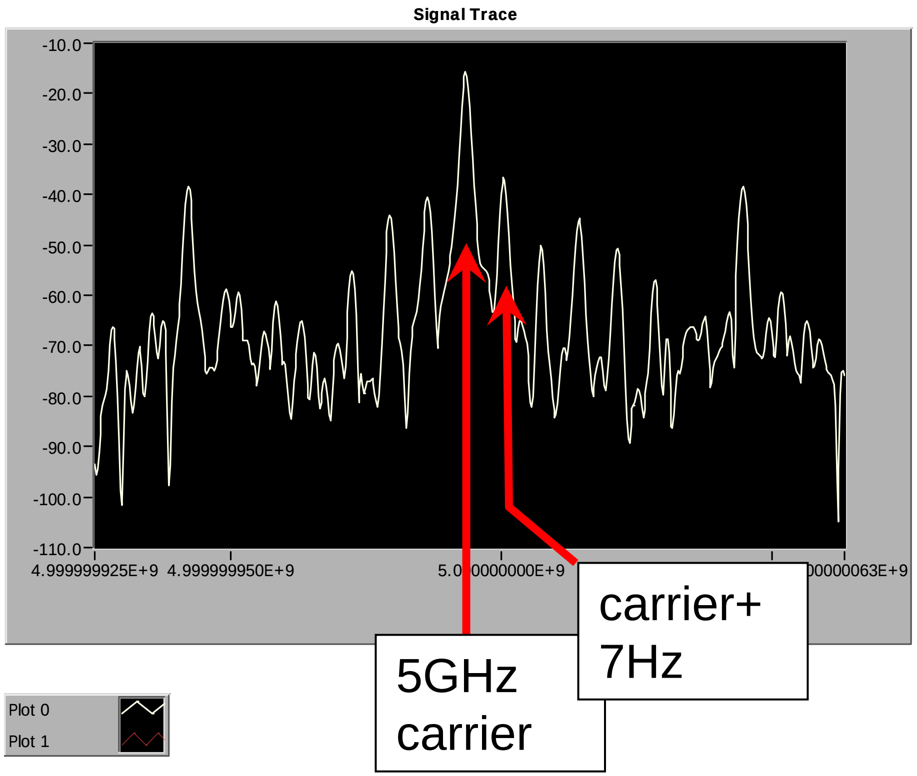
Remaining LRM spec related items

- Limits for laser mode-partition noise over operating temperature range and impact on modal noise, work in progress following results from task 2 and TP2.
- Laser relaxation oscillation and damping variation over operating temperature range and impact on jitter generation and jitter tolerance, work in progress following results from task 2 andTP2.

4) Vibration Testing 1: Set up & example spectrum

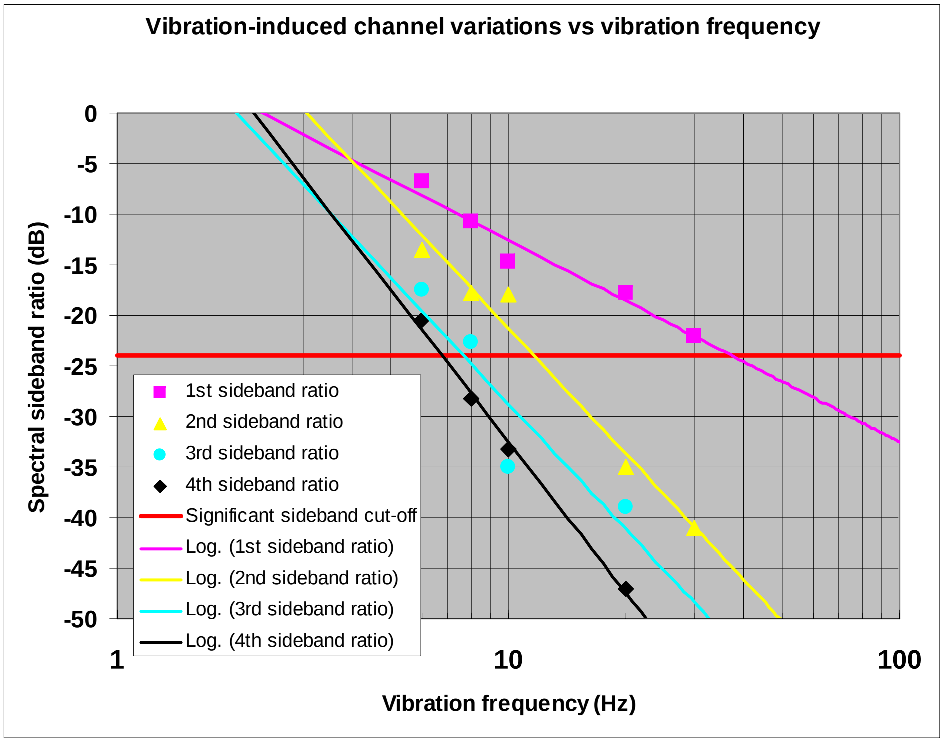
Ref: 'Time variance in MMF links - further test results', Rob Coenen

- A 10m MM fiber coil was suspended vertically (noted to be worst case) and mechanically shaken at various frequencies between 6 and 30 Hz. Mechanical vibration modulation sidebands on a 5GHz optical tone were recorded
  - Received signal spectrum for 7Hz vibration, 1g acceleration
  - Sidebands at 7, 14, 21 and 28Hz from signal tone.
  - Sideband ratios are -21, -28, -30 -35dB



4) Vibration Testing 2: Sideband level vs frequency

- Magnitude of channel variation drops rapidly with frequency
- Amplitude of physical movement of the fiber dictates the magnitude of the channel variations (not the rate at which it is moved).
- Effect of the 1st harmonic dominates over higher order harmonics



Conclusions

- Maximum channel variation frequency is **<40 Hz**, due to the 1st harmonic. The max channel variation frequency due to the 2nd harmonic is ~24Hz.
- For larger channel variations the maximum frequency is lower, the absolute amount depending upon the channel in question

5) Quasi-static impulse response measurements 1

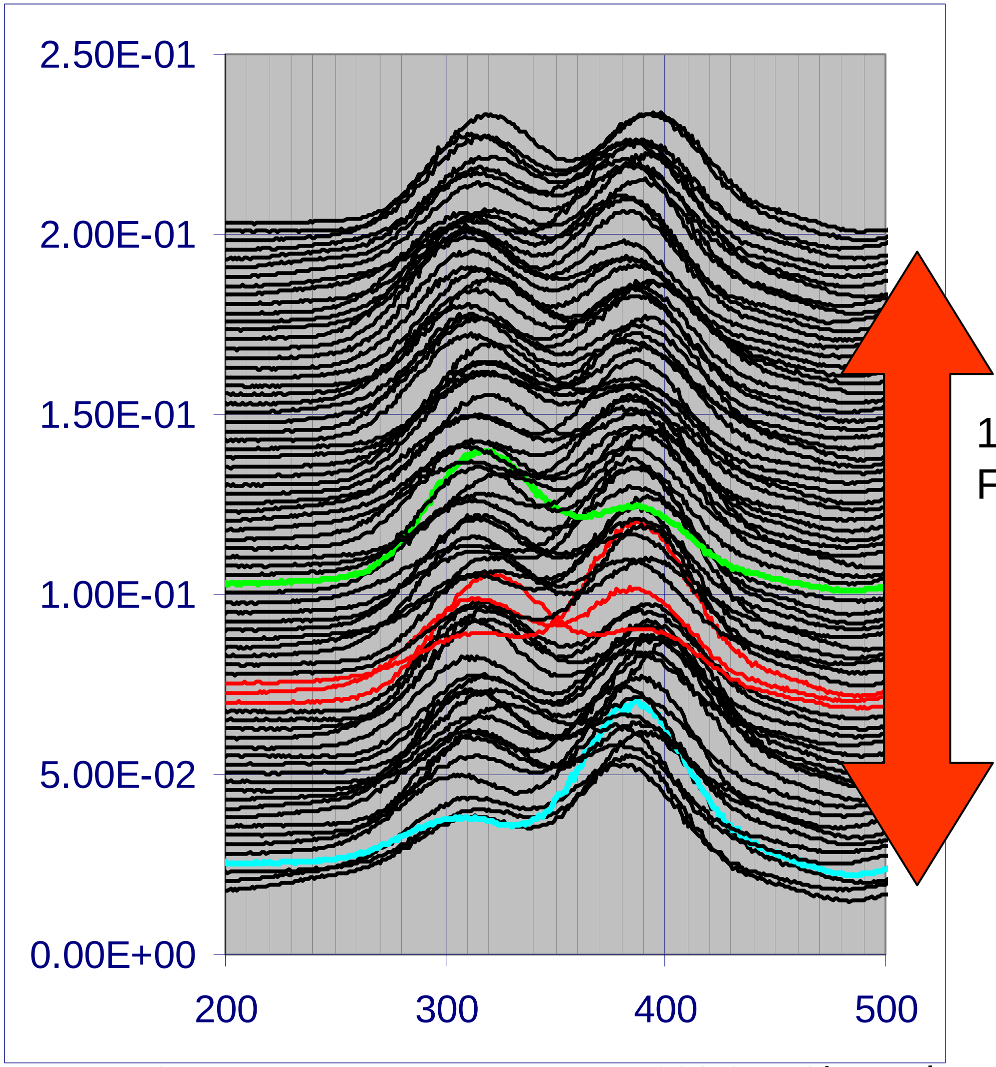
Ref: 'Experiments on time-variation due to polarization and MMF shaking and results', Jonathan King (More detailed talk later in king_2_1104)

- A polarisation scrambler, and single-mode and multi-mode fibre figure of 8 shakers were used at the input of a 300m MMF fibre, to study the effect of the polarisation effect and MMF perturbation on dynamic channel response A fibre and launch combination was selected to generate a 2 peaked impulse response with large IPR variation, and IPR evolution recorded

- Polarization effect found to
  - explore similar (smaller) IPR space as thorough MMF fibre shaker
    ...... no new channel responses !
  - power change in an IPR peak >> than mode selective loss
- Quasi-static IPR evolution measurements
  - Synchronously driven SMF plus MMF shaker used to provide full IPR exploration
    - shrinks quasi static measurements to linear measurement domain
    - includes polarisation and MMF mode mixing effects
    - representative of a perturbed patchcord

5) Quasi-static impulse response measurements 2

Impulse response sequence

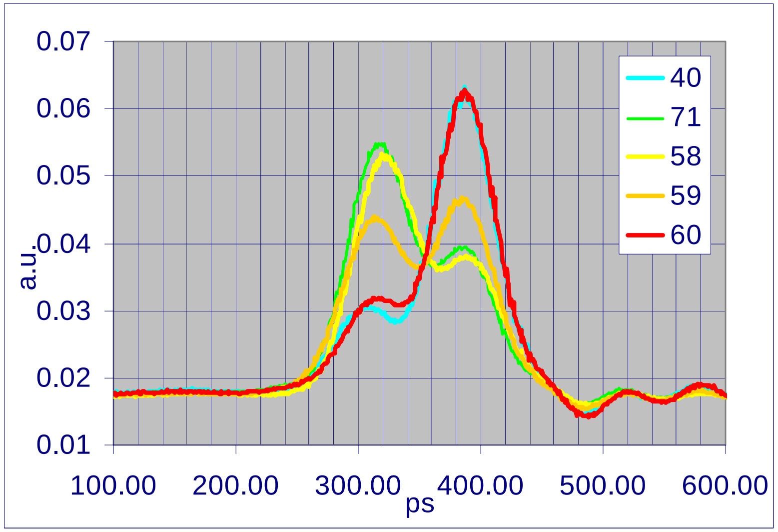


Fibre and launch selected for study:

7um offset centre launch gave 2 peaked IPR

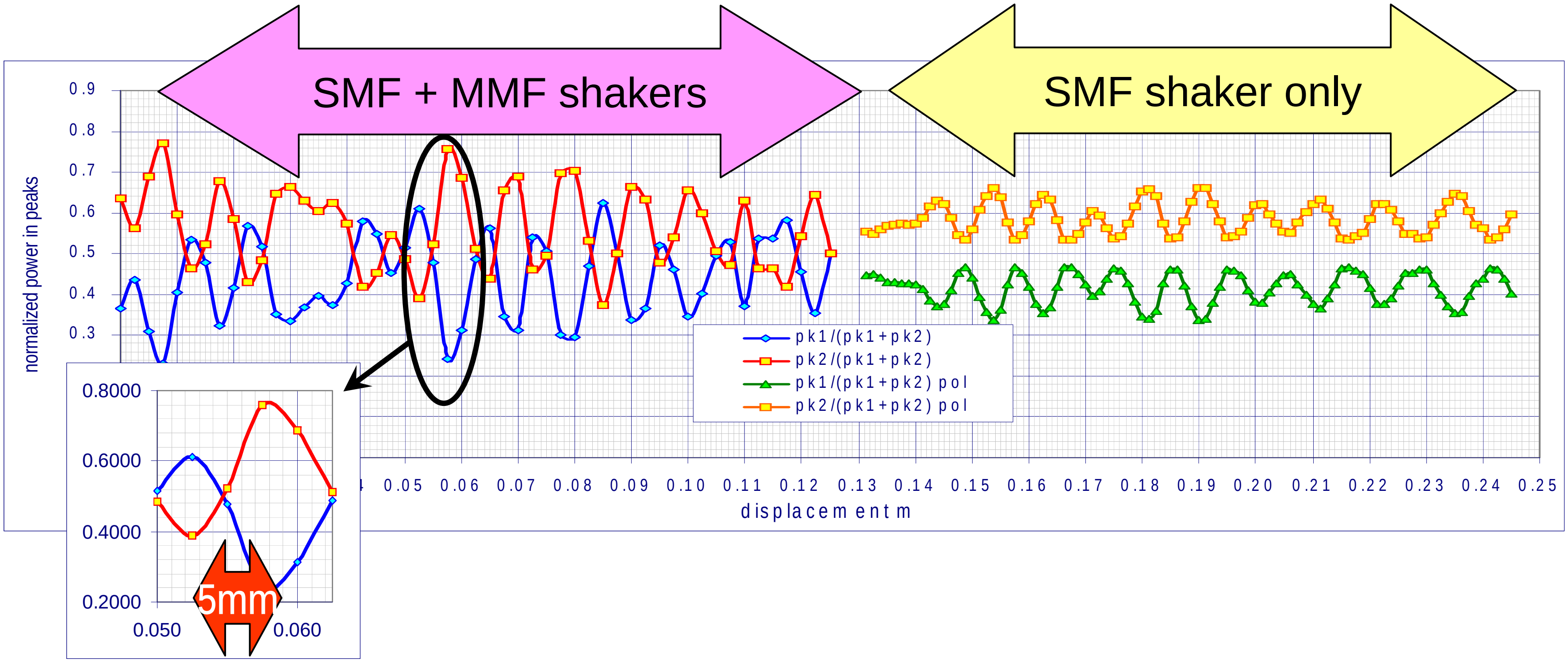
Causal to symmetric to anti-causal IPR variation possible

180mm total
Fo8 shaker movement



5) Quasi-static impulse response measurements 3

SMF + MMF shaker, vs SMF (polarisation effect) only



- Causal to anti-causal evolution in 5mm shaker movement
  - Similar rate of IPR evolution for SMF shaker only (polarisation effect only)
  - Polarization effect explores subset of IPRs explored with MMF + SMF shaker
- Following GR-63-CORE, equivalent to 10Hz vibration amplitude at 1g

6) Modal Noise

Ref: 'Improvements to Modal Noise Penalty Calculations', Petar Pepeljugoski et al
(More detailed talk later)

Modal noise theory has been adapted to better represent LRM applications and supports the 0.5dB maximum penalty allowance in the LRM link budget.

- For OSL launch into 50 and 62.5um fibre, modal noise penalty is below 0.5dB for up to 17um and 25um offset launches respectively.
- For a direct launch into OM3 fibres, modal noise penalty is below 0.5dB for an 86% encircled flux radius of up to 18um. This corresponds to <0.5dB modal noise penalty if total MSL through the link is <1.5dB

More details in Pepeljugoski_1_1104

Summary

4) Vibration experiments

- Low frequency vibration has most impact; 1^{st} vibration frequency harmonic dominates, higher orders are less significant
- 40 Hz is the estimated maximum rate at which any significant channel variations (-24dB sideband level) may occur under the office vibration conditions referenced in GR-63-CORE. Larger effects occur only at lower frequencies (-8dB at 10Hz)

5) Polarisation effect and quasi-static channel measurements

- Similar impact on channel as fibre perturbation - no new channel responses !
- Not reliant on MSL: power variation of IPR peaks >>MSL of link
  - Note: similar findings for 3 independent experimenter groups
- SMF + MMF fibre shaker experiments
  - similar IPR evolution rates vs displacement for SMF and MMF figure of 8 shakers
  - worst case IPR variation in 5mm shaker motion
  - would correspond to 10Hz vibration rate (GR-63-CORE)
    - suggests TP3 dynamic test rate of 10Hz for full IPR evolution

6) Modal Noise

- theory adapted to LRM application
- Shows 0.5dB modal noise penalty is conservative estimate of penalty

Task 2 Recommendations

- Modal Noise Penalty
  - 0.5dB seems sufficient for LRM
- Polarisation effect
  - Does not introduce any new penalties
  - Can be included in dynamic adaption requirements under mechanical vibration of input patchcord to link
  - Impact of effect can be bounded by experiment
- Dynamic channel rates of change
  - Low frequencies shown to have largest effect on channel response
    - e.g. 2 peak impulse response, worst case rate of change from 60:40 - 40:60 power split is up to 10Hz
  - Smaller changes at higher frequencies
    - e.g. 2 peak impulse response, worst case rate of change from 55:45 - 45:55 power split is up to 20Hz

Further info

Summary of temperature variation impact

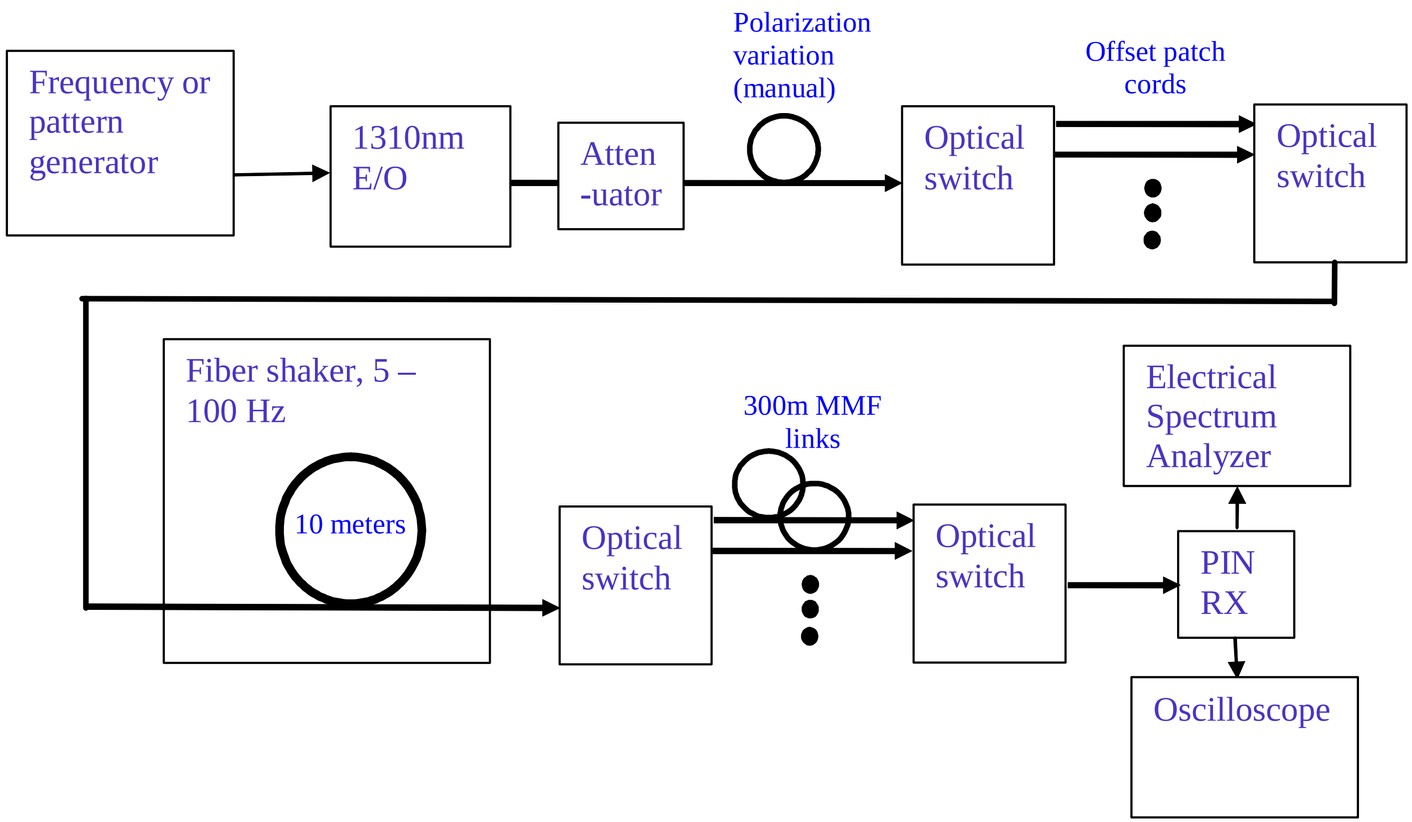
Ref: Popescu_02_0904

Varying Factor	Impact	Comments
Receiver temperature change	small	
Fiber length change over operating temperature range	small	
Fiber refractive index change over operating temperature range	small	
Connector attenuation change over operating temp. range	small	
Polarization change due to connector temperature range	needs review	will affect noise
Laser wavelength change over operating temp. range	small	
Laser polarization change over operating temp. range	small	
Laser relaxation oscillation and damping variation over operating temp range	small	will affect jitter
RIN variation over the operating temperature range	small	
Laser mode partition noise	needs review	will affect noise
Laser spot size change pver operating temperature range	small	design dependent

- Note 1: Temperature variation impact on time varying channel is small.
- Note 2: Laser polarization change and mode-partition noise change over the operating temperature range and impact on noise need more analysis.

Vibration experiment set up

Ref: 'Time variance in MMF links - further test results', Rob Coenen



- A 10m MM fiber coil was suspended vertically (worst case) and mechanically shaken at various frequencies between 6 and 30 Hz.